

APPENDIX D

Summary of Results

Phase 1 Biological Selenium Removal Treatment Technology Fluidized Bed Bioreactor

The first phase of the biological selenium removal treatment technology study involved setup and testing of the fluidized bed bioreactor (FBR) active biological treatment technology. Phase 1 was designed to evaluate the performance of the FBR and the ancillary filtration equipment operation and to demonstrate effective operation and treatment of 250 gallons per minute (gpm), with plans to subsequently increase the treatment capacity of the pilot system to the 2,000 gpm range (i.e., Phase 2). The study was conducted as specified in the *Phase 1 Work Plan/SAP for the Biological Selenium Removal Treatment Technology, Fluidized Bed Bioreactor* (Formation 2014), including subsequent Addenda 01 through 04 and specific updates to operational information and monitoring requirements. Monthly reports were submitted to the agencies through the course of the study, and included summaries of operational status and issues, along with presentation of preliminary laboratory and field data.

Results for Weeks 0-12 sampling (from March 2016 through June 2016) are summarized in this appendix as follows: (1) comparison of the results with the effluent design basis and estimated effluent quality values (see Table 2-3 [Formation 2014]), along with presentation of time-series plots; and (2) laboratory results for the full analytical suite, including proposed analytes for elimination. In addition, selenium concentrations at key locations downstream of the treatment facility are presented for: (1) no treatment (measured concentrations); (2) 250 gpm treatment (predicted concentrations); and (3) 2,000 gpm treatment (predicted concentrations).

Note that this appendix presents monitoring results from the Phase 1 study extending back to the initiation of the study in March 2015. Although most of the tables and figures include results from all of the sampling events since that time, the discussion focuses on results of environmental monitoring for Weeks 0-12 starting in March 2016. Results prior to March 2016 are not discussed because, after the initial startup in early 2015 and continuing into early 2016, there were several starts and stops with adjustments and additions made to the system to address operational issues including the hydraulics between the aeration tank and sand filter, occurrence of the filamentous sulfide-oxidizing bacteria, and excessive bio-film buildup in tanks (addressed by nutrient dosing). Because the results from March 2015 to March 2016 do not represent a long-term operational condition, this initial portion of the dataset was not evaluated in this appendix.

Comparison of the results with the effluent design basis and estimated effluent quality values:

The effluent design basis and estimated effluent quality values were presented in Table 2-3 of the Phase 1 FBR *Work Plan/SAP* (Formation 2014), and are compared with results of Weeks 0-12 sampling in Table 1. As shown, total selenium exceeded the design basis (0.005 mg/L) for influent measurements and most of the effluent measurements in this period. Total selenium concentrations in the effluent ranged from 0.00527 to 0.0106 (mean of 0.0083 mg/L) and in the influent ranged from 0.113 to 0.138 mg/L (mean of 0.126 mg/L), resulting in an average decrease in selenium concentrations of 93 percent.

Time-series plots for key design basis and effluent quality parameter results are provided in Figures 1 through 8. In addition, selenium loading rates and selenium removal during operation of the Phase 1 FBR, through June 2016, are presented in Figures 9 and 10, respectively.

Laboratory results for the full analytical suite, including proposed analytes for elimination:

As specified in Table 3-3 of the Phase 1 FBR *Work Plan/SAP* (Formation 2014), results from samples collected in Weeks 0-12 are to be evaluated for possible elimination of selected analytes from the Phase 1 full analytical suite as referenced in Table 3-4 (Formation 2014, updated in Addendum 01). Results from analysis of the Phase 1 full analytical suite are provided in Table 2. Analytes on the full list, with the exception of parameters listed in Table 2-3 (Pilot System Design Basis and Estimated Effluent Quality), were considered for elimination based on reasons shown at the bottom of Table 2, as follows:

- A If all results are non-detect for each of the 7 events.
- B If concentration is equivalent or decreases from influent to effluent for each of the 7 events.
- C If the maximum Relative Percent Difference (RPD) between influent and effluent results is <10 percent for each of the 7 events.
- D If the maximum RPD between influent and effluent results is <20 percent for each of the 7 events, but 10-20 percent for at least 1 event.
- E If the maximum RPD between influent and effluent results is <20 percent for 6 of the 7 events.
- F Parameter proposed for elimination due to requirement for analysis in Weeks 0-12 only.

For Weeks 0-12, the following Phase 1 analytes were not detected in the influent and effluent (total and dissolved for all): aluminum, beryllium, cadmium, lead, silver, and thallium. For the same period, the following Phase 1 analytes were equivalent or decreased from influent to effluent, or some of the results were not detected (total and dissolved for all): arsenic, barium, chromium, and vanadium. Also, the following Phase 1 analytes had a minimal change (based on calculated RPDs) between the influent and effluent: bicarbonate, calcium (dissolved), magnesium (dissolved), potassium (dissolved), sodium (dissolved), fluoride, and boron (total and dissolved).

Based on results from samples collected during the early stages of Phase 1 operation and testing, prior to Weeks 0-12 starting in March 2016, the Forest Service previously approved removal of organic selenium species (dimethyl-selenide and dimethyl-diselenide) from the Phase 1 full analytical suite (Table 3-4 [Formation 2014]) via email from Sherri Stumbo to Monty Johnson on April 22, 2016; Simplot provided revised Table 3-4 (April 27, 2016) to the Forest Service.

While review of the Phase 1 Pilot Study results shows that a number of analytes in the full analytical suite could be proposed for elimination from Phase 1 monitoring, the full analytical suite used for Phase 1 (Weeks 0-12 and quarterly) will also be used for Phase 2 (Weeks 0-12). After the results for Phase 2 (Weeks 0-12) are received, the Phase 2 dataset will be evaluated and specific analytes may be proposed for elimination at that time.

Selenium concentrations at key locations downstream of the treatment facility:

As specified in Table 3-3 of the Phase 1 FBR *Work Plan/SAP* (Formation 2014), expected selenium concentrations at key locations downstream of the treatment facility were calculated. Results are

presented in Table 3 for: (1) no treatment (measured concentrations); (2) 250 gpm treatment (predicted concentrations); and (3) 2,000 gpm treatment (predicted concentrations). Under low-flow conditions (results from November 2015 sampling event), measured selenium concentrations (with no treatment) at LSV-4 (Sage Creek, just upstream of Crow Creek), CC-1A (Crow Creek, just downstream from Sage Creek inflow), and CC-WY-01 (Crow Creek at the state line) are 0.047, 0.02, and 0.018 mg/L. During operation of the treatment facility at a capacity of 250 gpm, predicted selenium concentrations at these three locations, under low-flow conditions, are 0.043, 0.018, and 0.016 mg/L, respectively. Under a treatment scenario with a capacity of 2,000 gpm and an assumed effluent concentration similar to the Phase 1 measured effluent, predicted selenium concentrations at these three locations, under low-flow conditions, are 0.015, 0.0068, and 0.0051 mg/L, respectively (a reduction of approximately 70 percent).

Reference cited:

Formation, 2014. Work Plan/Sampling and Analysis Plan (SAP) for the Biological Selenium Removal Treatment Technology, Fluidized Bed Bioreactor. Includes subsequent Addenda 01 through 04. Prepared for the J.R. Simplot Company. September.

Table 1. Results for Selected Parameters Measured During FBR Treatment, Weeks 0-12

Station	Testing Period	Week	Date	Selected Parameters With Effluent Design Basis						Estimated Effluent Quality		
				Nitrate as N mg/L	Selenium, Total mg/L	Total Phos. as P mg/L	Total Sulfide mg/L	TSS mg/L	Dissolved Oxygen mg/L	Sulfate as SO4 mg/L	TDS mg/L	Temperature degrees C
Effluent	March 2015	0	3/18/2015	0.05	0.0108	0.188		5	8.01	56.5	288	12.02
Effluent	March 2015	2	3/31/2015	0.05	0.0038	0.077		5	5.74	48.4	275	11.66
Effluent	July 2015	0	7/17/2015		0.00297	0.005						
Effluent	July 2015	1	7/21/2015	0.09	0.00382	0.0923	1	5	6	26.6	266	14.34
Effluent	July 2015	2	7/28/2015	0.07	0.0303	0.067	1	5	7.38	34.6	230	12.67
Effluent	Oct-Nov 2015	0	10/21/2015	0.12	0.00885	0.0604	1	2	8.85	32.2	276	12.33
Effluent	Oct-Nov 2015	1	10/28/2015	0.12	0.00979	0.161	1	3	10.74	32.3	266	12.47
Effluent	Oct-Nov 2015	2	11/4/2015	0.11	0.01	0.0513	1		8.91			12.41
Effluent	Oct-Nov 2015	3	11/10/2015	0.13	0.00931	0.168	1	2	8.26	29.6	278	13.06
Effluent	Oct-Nov 2015	4	11/18/2015	0.13	0.00773	0.0396	1		7.98			13.03
Effluent	Oct-Nov 2015	5	11/24/2015	0.04	0.00807	0.0423	1		8.5			13
Effluent	Jan-Feb 2016	0	1/27/2016	0.03	0.00335	0.0551	1	2	10.58	41.2	296	12.12
Effluent	Jan-Feb 2016	1	2/3/2016	0.11	0.0112	0.0258	1	2	8.58	45.8	362	12.13
Effluent	Since Mar 2016	0	3/30/2016	0.04	0.00999	0.135	1	2	8.03	47.3	240	12.15
Effluent	Since Mar 2016	1	4/6/2016	0.05	0.00859	0.148	1	2	7.68	49.3	292	12.31
Effluent	Since Mar 2016	2	4/13/2016	0.04	0.00843	0.151	1		6.45			12.28
Effluent	Since Mar 2016	3	4/20/2016	0.12	0.0094	0.0917	1	2	6.67	46.8	232	12.37
Effluent	Since Mar 2016	4	4/28/2016	0.12	0.00894	0.0784	1		6.17			12.19
Effluent	Since Mar 2016	5	5/5/2016	0.03	0.0106	0.1	1	2	3.75	64	302	13.81
Effluent	Since Mar 2016	6	5/11/2016	0.13	0.00802	0.147	1		6.27			12.57
Effluent	Since Mar 2016	7	5/25/2016	0.11	0.00884	0.107	1	2	8.6	46.3	318	12.47
Effluent	Since Mar 2016	8	6/1/2016	0.13	0.0101	0.185	1		8.01			13.08
Effluent	Since Mar 2016	9	6/7/2016	0.03	0.00527	0.109	1	2	7.26	43	284	13.16
Effluent	Since Mar 2016	10	6/15/2016	0.1	0.00542	0.148	1		7.42			12.97
Effluent	Since Mar 2016	11	6/21/2016	0.12	0.00677	0.13	1	2	7.49	38	258	12.92
Effluent	Since Mar 2016	12	6/28/2016	0.13	0.00707	0.121	1		7.59			12.81
Influent	March 2015	0	3/18/2015	0.315	0.126	0.01		5	5.96	56.7	289	12.03
Influent	March 2015	2	3/31/2015	0.327	0.11	0.01		9	6	57.1	272	12.3
Influent	July 2015	0	7/17/2015		0.102	0.0154						
Influent	July 2015	1	7/21/2015	0.33	0.103	0.0558	1	5	6.06	32.4	270	12.48
Influent	July 2015	2	7/28/2015	0.34	0.112	0.0334	1	5	8.24	37	226	12.86
Influent	Oct-Nov 2015	0	10/21/2015	0.34	0.114	0.02	1	2	6.32	36	276	12.08
Influent	Oct-Nov 2015	1	10/28/2015	0.34	0.117	0.0285	1	2	7.42	34.9	198	12.28
Influent	Oct-Nov 2015	2	11/4/2015	0.33	0.118	0.0543	1		8.29			12.19
Influent	Oct-Nov 2015	3	11/10/2015	0.33	0.123	0.0355	1	2	7.63	36.6	252	12.08
Influent	Oct-Nov 2015	4	11/18/2015	0.34	0.117	0.0229	1		7.96			12.51
Influent	Oct-Nov 2015	5	11/24/2015	0.34	0.119	0.027	1		7.57			12.62
Influent	Jan-Feb 2016	0	1/27/2016	0.35	0.136	0.0398	1	2	11.46	43.6	298	12.3
Influent	Jan-Feb 2016	1	2/3/2016	0.32	0.125	0.04	1	2	7.44	41.3	344	12.59
Influent	Since Mar 2016	0	3/30/2016	0.33	0.132	0.0353	1	2	7.95	43.9	262	11.95
Influent	Since Mar 2016	1	4/6/2016	0.43	0.113	0.0255	1	2	8.24	42.1	448	12.52
Influent	Since Mar 2016	2	4/13/2016	0.41	0.122	0.0161	1		8.35			12.73
Influent	Since Mar 2016	3	4/20/2016	0.41	0.13	0.0228	1	2	7.61	40.6	246	12.55
Influent	Since Mar 2016	4	4/28/2016	0.95	0.122	0.0184	1		7.42			12.35
Influent	Since Mar 2016	5	5/5/2016	0.41	0.127	0.0206	1	2	4.55	46.4	306	12.43
Influent	Since Mar 2016	6	5/11/2016	0.44	0.124	0.0321	1		6.95			12.82
Influent	Since Mar 2016	7	5/25/2016	0.39	0.114	0.025	1	2	9.51	43.3	292	12.77
Influent	Since Mar 2016	8	6/1/2016	0.43	0.134	0.0377	1		8.77			12.56
Influent	Since Mar 2016	9	6/7/2016	0.42	0.125	0.0411	1	2	8.61	42.7	284	12.63
Influent	Since Mar 2016	10	6/15/2016	0.41	0.138	0.0166	1		8.59			13.29
Influent	Since Mar 2016	11	6/21/2016	0.38	0.124	0.0265	1	2	8.74	34.1	278	13.59
Influent	Since Mar 2016	12	6/28/2016	0.41	0.132	0.0315	1		8.6			13.64

Effluent Design Basis Non-Detect Values <5 ≤0.005 <0.25 <1 <5 Saturation Field <100 3-10 <400 10 8 to 17 Field

Note: Results shown in bold and shading exceed corresponding design basis values.

Table 2. Laboratory Results, Full Analytical Suite Analyses - Hoopes Treatability Study Pilot (Weeks 0-12)

Analyte	Units	Week 0		Week 1		Week 3		Week 5		Week 7		Week 9		Week 11		Suggested Removal - Reason Code	RPD Wk0	RPD Wk1	RPD Wk3	RPD Wk5	RPD Wk7	RPD Wk9	RPD Wk11		
		Station >>	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent									
General Chemistry																									
Ammonia as N	mg/L	2	0.026 U	1.33	0.026 U	1.65	0.026 U	1.24	0.026 U	1.32	0.026 U	0.96	0.026 U	1	0.026 U	0.386									
Bicarbonate	mg/L		160	170	200	160	200	180	180	190	200	170	180	190	180		E	6%	22%	11%	0%	5%	6%	5%	
Biochemical Oxygen Demand	mg/L	10	2 U	5	2 U	26	2 U	2	2 U	4	2 U	2	2 U	7	2 U	2 U									
Carbonate	mg/L		1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U			0%	0%	0%	0%	0%	0%	0%	
Chemical Oxygen Demand	mg/L	5 U	5	5 U	5	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U	7		0%	0%	0%	0%	0%	0%	33%	
Calcium, Dissolved	mg/L		61	61.3	62.7	62.9	57.8	57.1	59.2	58.8	59.6	59.8	58.2	57.3	62.4	61.6	C	0%	0%	1%	0%	2%	1%		
Magnesium, Dissolved	mg/L		22.3	22.1	23	22.9	21.7	21.6	22.2	22.3	21.9	22	23.1	22.8		C	1%	0%	0%	0%	0%	0%	1%		
Potassium, Dissolved	mg/L	0.687	0.649	0.615	0.665	0.549	0.528	0.658	0.681	0.637	0.554	0.615	0.576	0.702	0.656		C	6%	8%	4%	3%	14%	7%	7%	
Sodium, Dissolved	mg/L	5.97	6.05	5.78	6.49	6.14	6.18	5.63	6.39	5.46	5.39	5.33	5.56	5.46		D	1%	12%	1%	13%	4%	2%			
Chloride	mg/L	7.85	13.5	7.87	13.5	7.62	14.5	8.12	13.9	8.19	15.6	7.9	14.9	6.25	13		53%	53%	62%	52%	62%	61%	70%		
Fluoride	mg/L	0.271	0.289	0.275	0.255	0.266	0.222	0.265	0.26	0.217	0.273	0.265	0.259	0.219	0.196		E	6%	8%	18%	2%	23%	2%	11%	
Hardness	mg/L	300	244	244	251	234	232	236	235	240	241	235	234	251	247										
Nitrate as N	mg/L	5	0.33	0.04 J	0.43	0.05 J	0.41	0.12	0.41	0.03 J	0.39	0.11	0.42	0.03 J	0.38										
Nitrate/Nitrite as N	mg/L	5	0.328	0.0376 J	0.432	0.0495 J	0.408	0.124	0.412	0.0309 J	0.393	0.106	0.42	0.0311 J	0.377										
Sulfate	mg/L	100	43.9	47.3	42.1	49.3	40.6	46.8	46.4	64	43.3	46.3	42.7	43	34.1										
Alkalinity, Total as CaCO ₃	mg/L	> 50	160	170	200	160	200	180	180	190	200	170	180	190	180										
Total Dissolved Solids	mg/L	400	262	240	448	292	246	306	302	292	318	284	278	258											
Total Organic Carbon	mg/L		0.64 J	0.932 J	0.5 U	1.04	0.5 U	0.949 J	0.513 J	0.957 J	0.5 U	0.962 J	0.5 U	0.839 J	0.5 U	0.784 J		37%	70%	62%	60%	63%	51%	44%	
Total Phosphorus as P	mg/L	0.25	0.0353	0.135	0.0255	0.148	0.0228	0.0917	0.0206	0.1	0.025	0.107	0.0411	0.109	0.0265	0.13									
Total Sulfide	mg/L	1	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U	1 U										
Total Suspended Solids	mg/L	5	2 U	2 U	2 U	2 J	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U	2 U										
Metals and Metalloids																									
Aluminum, Dissolved	mg/L		0.0076 U	0.0076 U	0.0076 U	0.0076 U	0.0076 U	0.0076 U	0.0076 U	0.0076 U	0.0076 U	0.0076 U	0.0076 U	0.0076 U	0.0076 U	A	0%	0%	0%	0%	0%	0%	0%	0%	
Aluminum, Total	mg/L		0.0076 U	0.0076 U	0.0076 U	0.0076 U	0.0076 U	0.0076 U	0.0076 U	0.0076 U	0.0076 U	0.0076 U	0.0076 U	0.0076 U	0.0076 U		A	0%	0%	0%	0%	0%	0%	0%	
Antimony, Dissolved	mg/L	0.0000732 U	0.00014 J	0.0000732 U	0.00011 J	0.00011 J	0.00012 J	0.0000732 U	0.00009 J	0.00011 J	0.00009 J	0.00015 J	0.0001 J	0.00021 J			63%	40%	9%	0%	20%	50%	71%		
Antimony, Total	mg/L	0.00024 J	0.00016 J	0.0000732 U	0.00012 J	0.0001 J	0.00012 J	0.0000732 U	0.0001 J	0.00011 J	0.0001 J	0.00016 J	0.00011 J	0.0002 J			40%	48%	18%	0%	10%	46%	58%		
Arsenic, Dissolved	mg/L	0.00042 J	0.000398 U	0.000398 U	0.000398 U	0.000398 U	0.000398 U	0.000398 U	0.000398 U	0.000398 U	0.000398 U	0.000398 U	0.000398 U	0.000398 U	0.000398 U		B	5%	0%	0%	0%	0%	0%	0%	
Arsenic, Total	mg/L	0.00047 J	0.000398 U	0.000398 U	0.000398 U	0.000398 U	0.000398 U	0.000398 U	0.000398 U	0.000398 U	0.000398 U	0.000398 U	0.000398 U	0.000398 U	0.000398 U		B	17%	0%	0%	3%	3%	0%	0%	
Barium, Dissolved	mg/L	0.051	0.0358	0.0478	0.0318	0.0503	0.0344	0.0445	0.0312	0.0459	0.0341	0.0486	0.0329	0.0475			B	35%	40%	38%	35%	39%	36%		
Barium, Total	mg/L	0.0534	0.0372	0.0489	0.0329	0.0508	0.0351	0.0455	0.0319	0.0518	0.0377	0.05	0.034	0.0474			B	36%	39%	37%	35%	32%	38%	33%	
Beryllium, Dissolved	mg/L	0.000047 U	0.000047 U	0.000047 U	0.000047 U	0.000047 U	0.000047 U	0.000047 U	0.000047 U	0.000047 U	0.000047 U	0.000047 U	0.000047 U	0.000047 U	0.000047 U		A	0%	0%	0%	0%	0%	0%	0%	
Beryllium, Total	mg/L	0.000047 U	0.000047 U	0.000047 U	0.000047 U																				

Table 3. Predicted Selenium Concentrations at Key Locations Downstream of the Treatment Facility**No Selenium Removed by Treatment Plant**

Measured Downstream Total Selenium Water Quality	High Flow		Low Flow	
	Load (lb/day)	Concentration (mg/L)	Load (lb/day)	Concentration (mg/L)
LSV-4	5.6	0.023	4.1	0.047
CC-1A	5.4	0.011	4.2	0.020
CC-WY-01	5.0	0.010	3.9	0.018

Selenium Removed By The Treatment Plant Operating at 250 gpm, Phase 1 Effluent Quality

Flow	250	gpm
Influent Concentration	0.124	mg/L
Effluent Concentration	0.00802	mg/L
Influent Load	0.37	lb/day
Effluent Load	0.02	lb/day
Load Removed	0.35	lb/day

Predicted Downstream Total Selenium Water Quality	High Flow		Low Flow	
	Load (lb/day)	Concentration (mg/L)	Load (lb/day)	Concentration (mg/L)
LSV-4	5.3	0.0216	3.8	0.0430
CC-1A	5.1	0.0103	3.9	0.0183
CC-WY-01	4.7	0.0093	3.5	0.0164

Selenium Removed By The Treatment Plant Operating at 2,000 gpm, Phase 1 Effluent Quality

Flow	2000	gpm
Influent Concentration	0.124	mg/L
Effluent Concentration	0.00802	mg/L
Influent Load	2.98	lb/day
Effluent Load	0.19	lb/day
Load Removed	2.79	lb/day

Predicted Downstream Total Selenium Water Quality	High Flow		Low Flow	
	Load (lb/day)	Concentration (mg/L)	Load (lb/day)	Concentration (mg/L)
LSV-4	2.9	0.0116	1.3	0.0151
CC-1A	2.6	0.0053	1.4	0.0068
CC-WY-01	2.2	0.0044	1.1	0.0051

Figure 1. Total Selenium, Hoopes Treatability Study

Water Sources: HS, HS-C1, LSS-SP-N

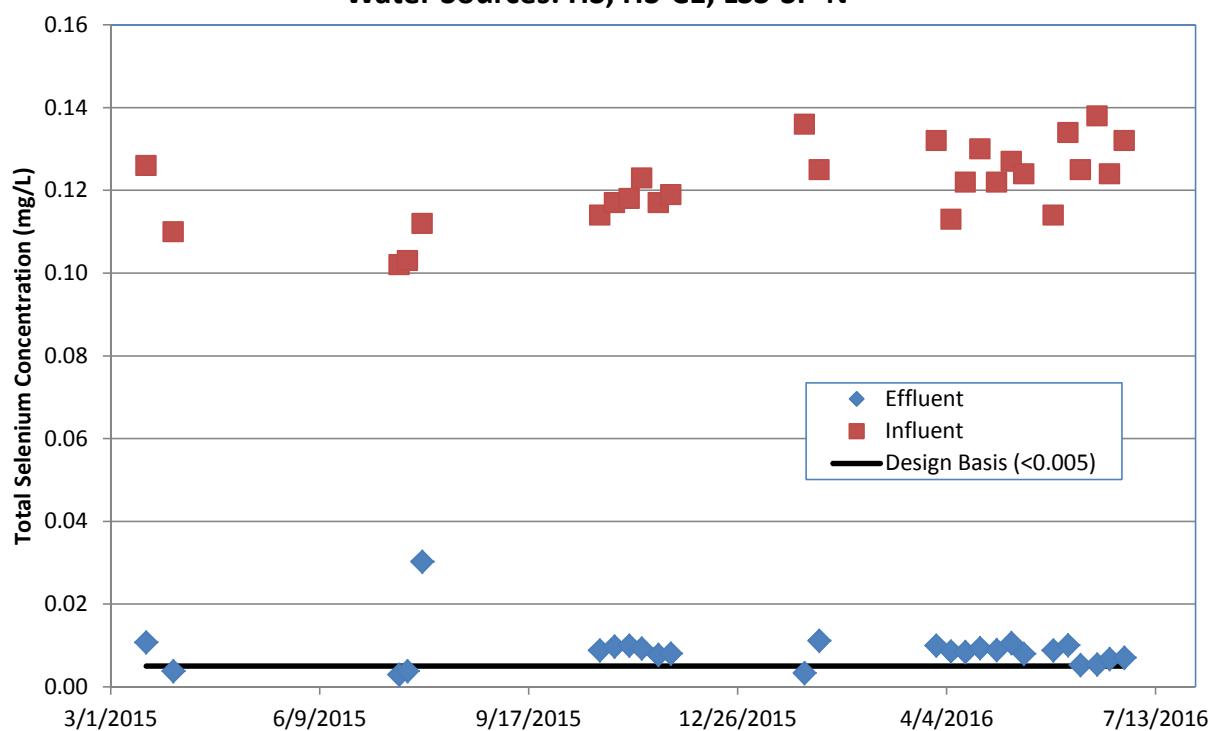


Figure 2. Nitrate as N, Hoopes Treatability Study

Water Sources: HS, HS-C1, LSS-SP-N

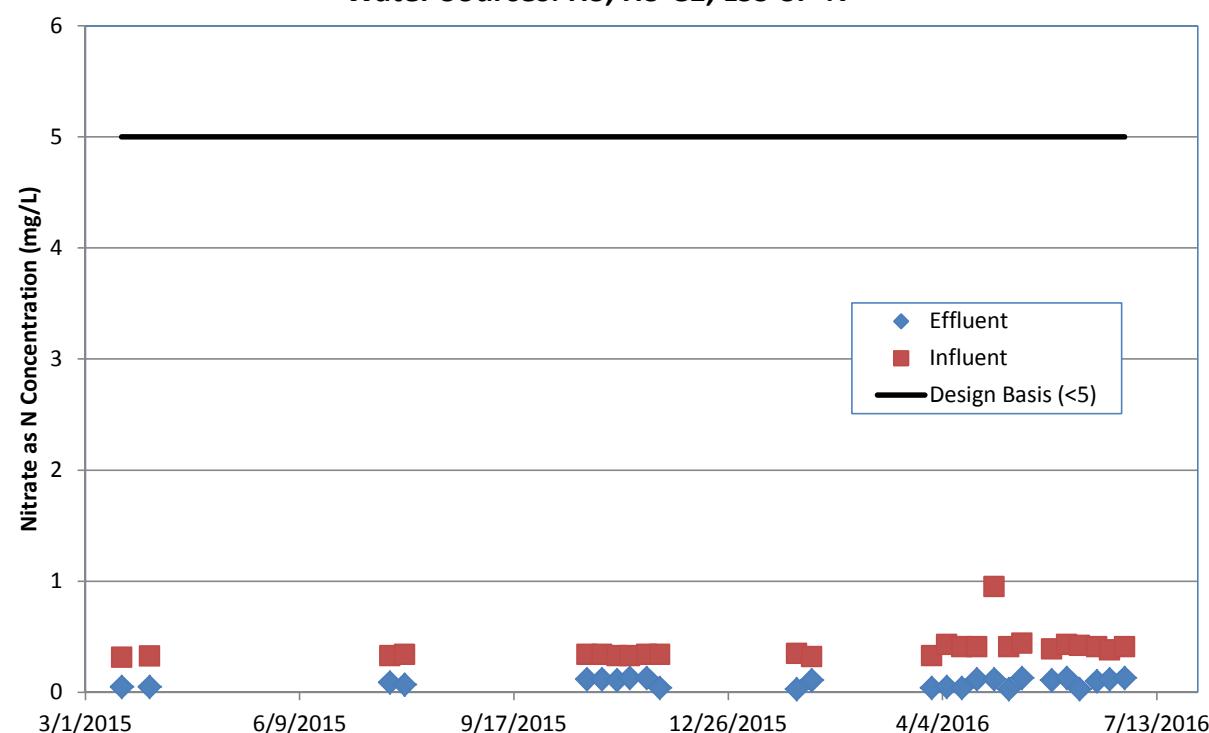


Figure 3. Total Phosphorus as P, Hoopes Treatability Study

Water Sources: HS, HS-C1, LSS-SP-N

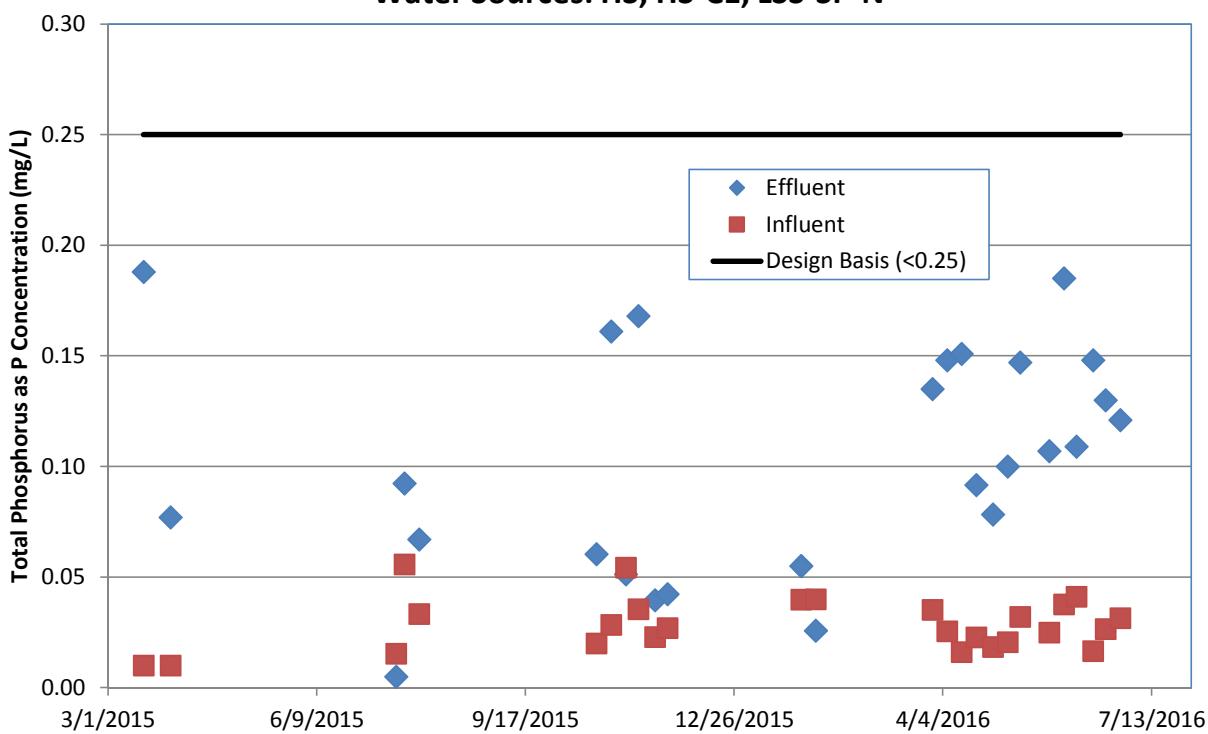


Figure 5. Dissolved Oxygen, Hoopes Treatability Study

Water Sources: HS, HS-C1, LSS-SP-N

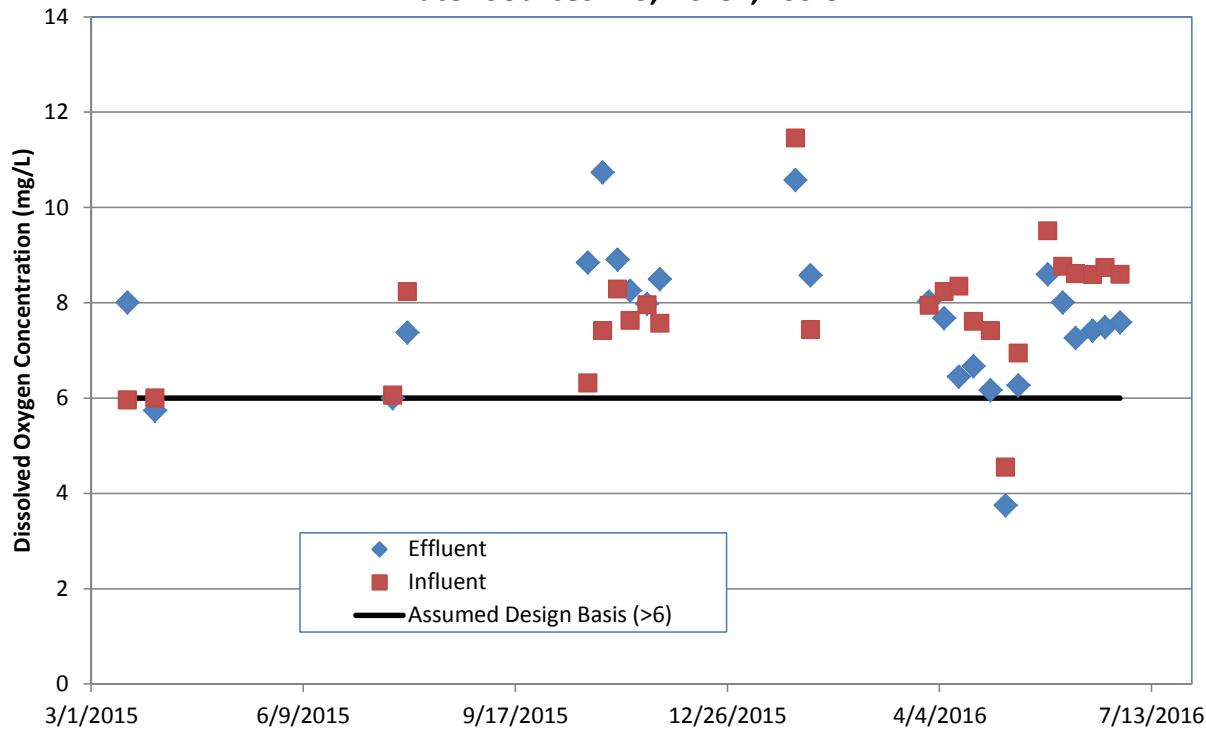


Figure 6. Sulfate as SO₄, Hoopes Treatability Study

Water Sources: HS, HS-C1, LSS-SP-N

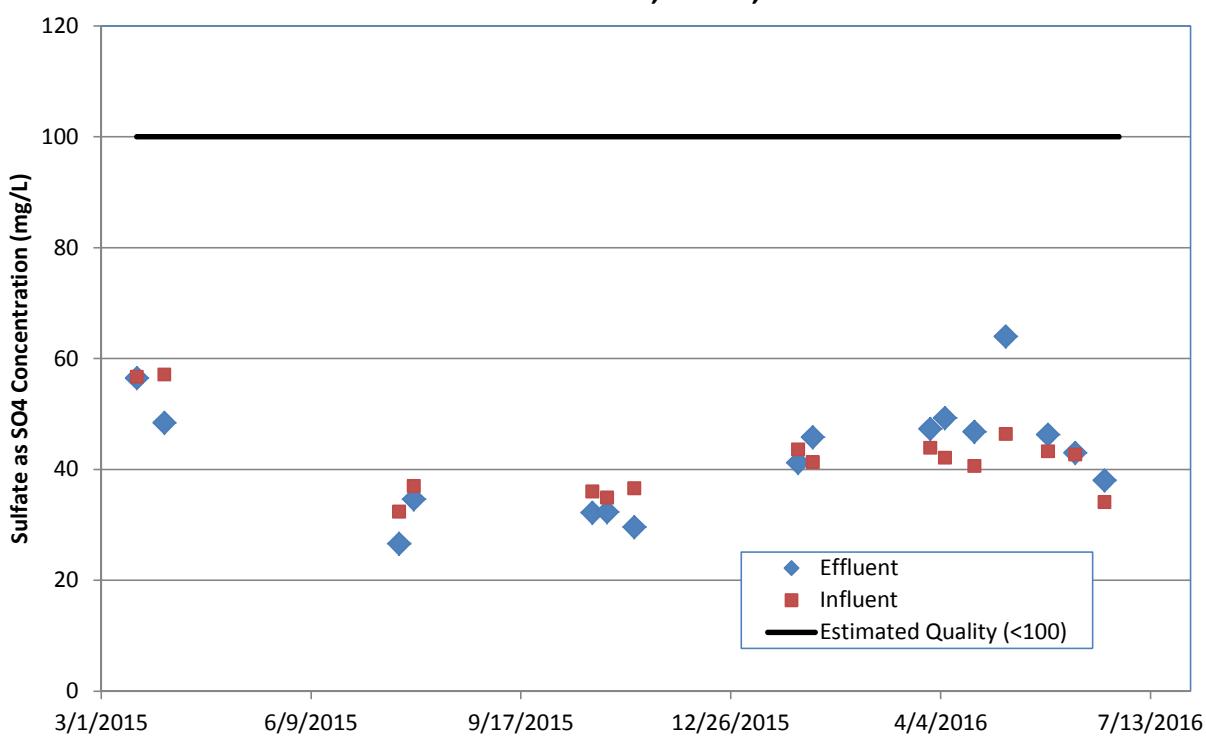


Figure 7. Total Dissolved Solids, Hoopes Treatability Study

Water Sources: HS, HS-C1, LSS-SP-N

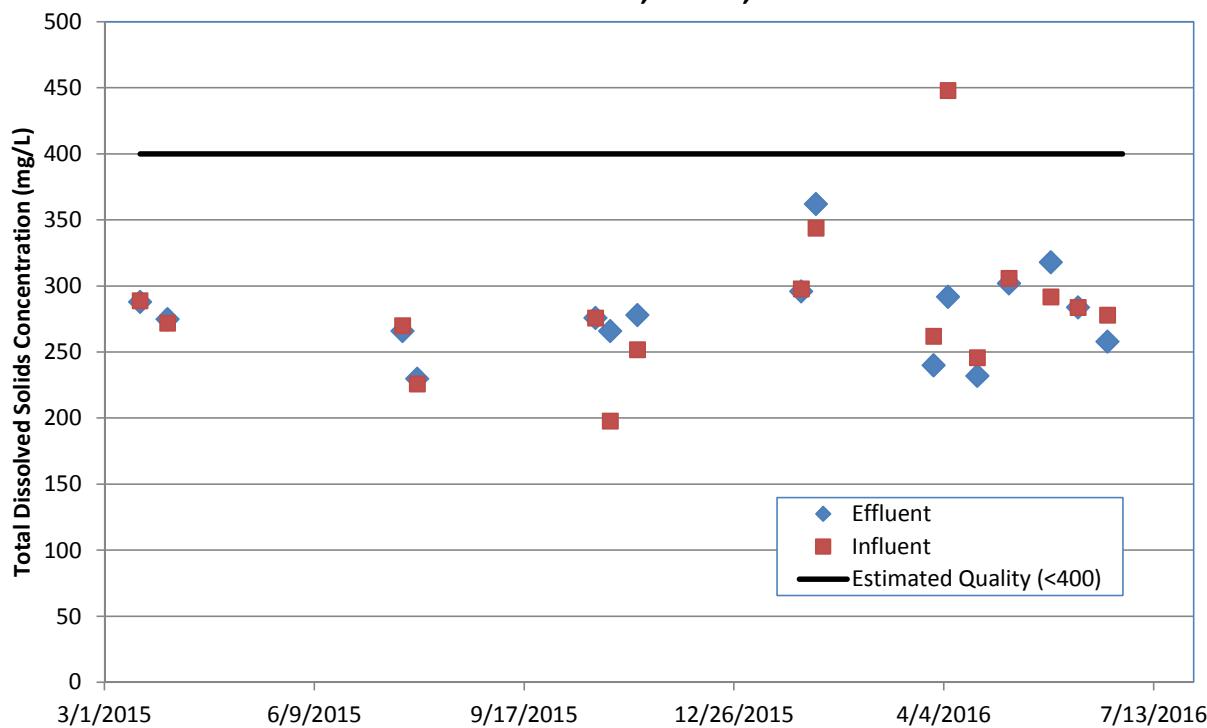
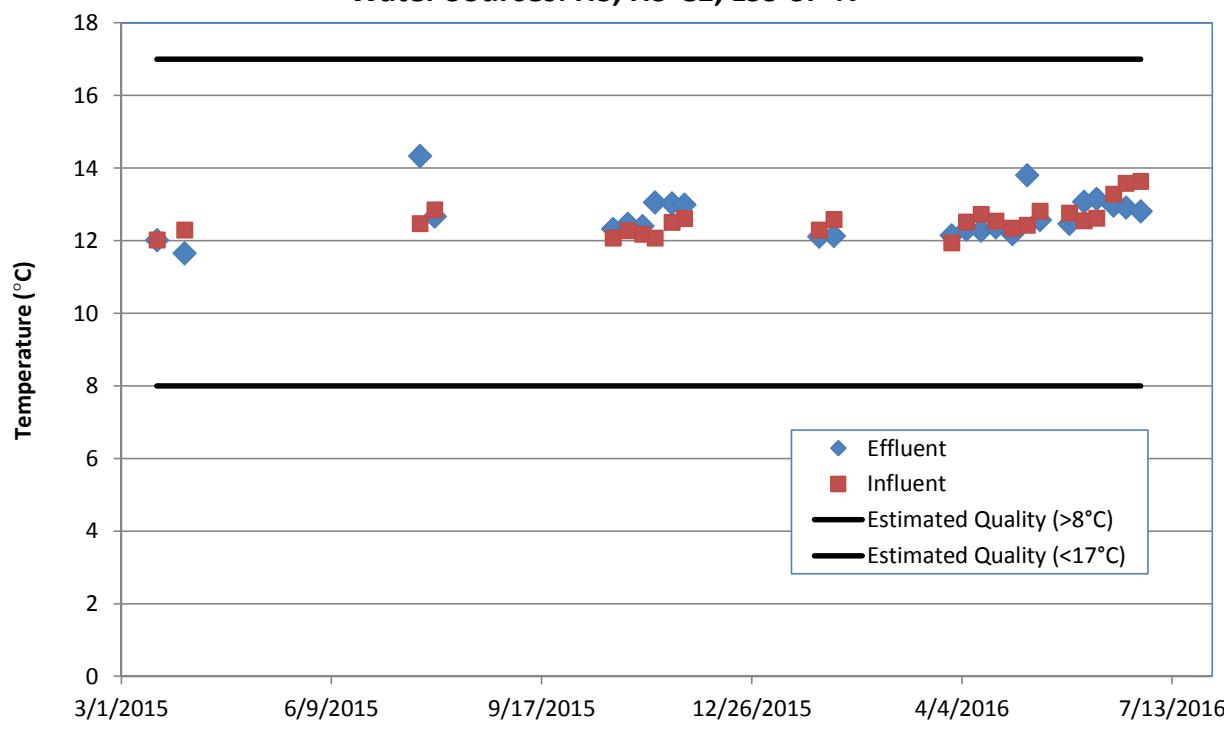


Figure 8. Temperature, Hoopes Treatability Study

Water Sources: HS, HS-C1, LSS-SP-N



**Figure 9. Selenium Loading Rates During FBR Treatment
Water Sources: HS, HS-C1, LSS-SP-N**

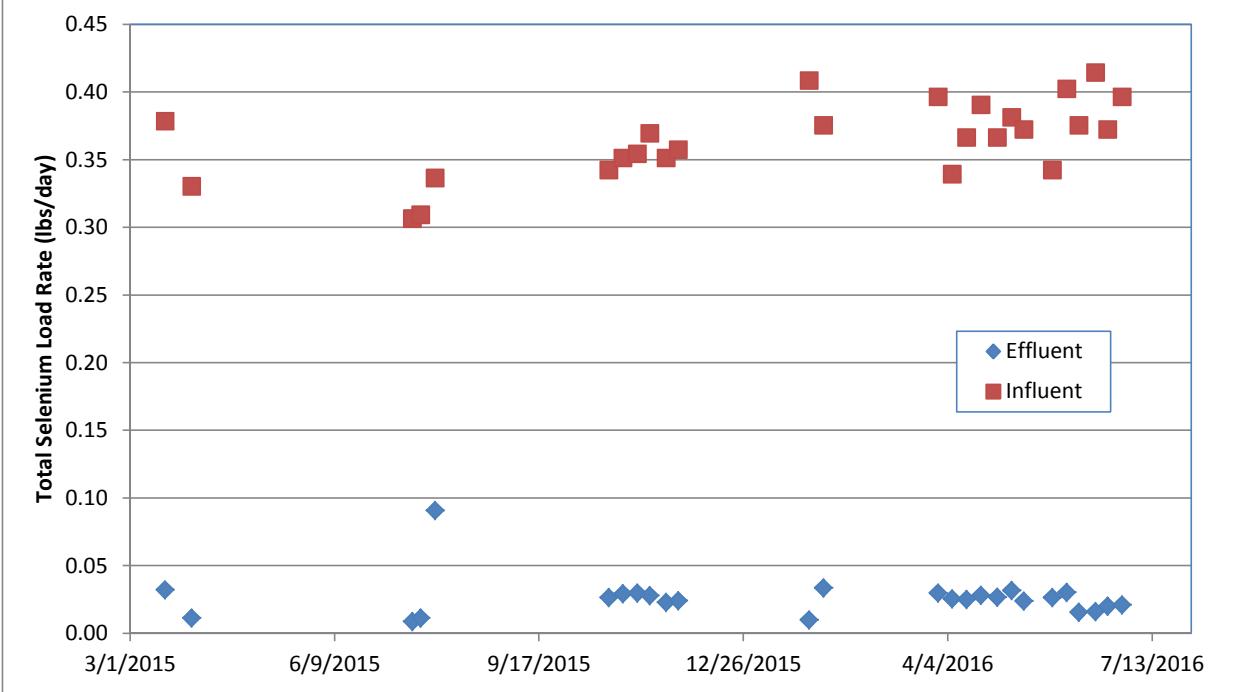


Figure 10. Removed Selenium Loading During FBR Treatment
Water Sources: HS, HS-C1, LSS-SP-N

